SANITARY ENGINEERING

Sanitization of biosolids from chemically enhanced primary treatment plant: composting or alkali stabilization?

INGENIERIA SANITARIA

Sanitización de biosólidos de plantas de tratamiento primario avanzado: ¿compostaje o estabilización alcalina?

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Abstract
This study was aimed at evaluating two pathogen reduction alternatives: composting and alkali stabilization of biosolids at the Cañaveralejo Wastewater Treatment Plant (PTAR-C), based in Cali, Colombia. Composting was used (biosolids; Filter press mud; biosolids (B) + filter press mud (C) + pruning trees (P); biosolids (B) + Organic waste from open market (ROPM) + pruning trees (P)) for a 61-days period**.** Alkali treatment was carried out for 13 days. Slaked lime and coal ash were applied to the biosolids and final products of composting. 8, 15 and 30 % (weight/weight) were the concentrations used for hydrated lime and ash. For both treatments pH, humidity, temperature, Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Ammonium Nitrogen (N-NH_4), helminth eggs, and Faecal Coliforms (FC) were monitored. The results showed that the better compost was (B+C+P) removed pathogens, but compost remained as a class B category, with geometric mean for FC of $4x10^3$ UFC g^{-1}, indicating that the process cannot achieve a class A category. Alkali stabilization showed that coal ash produced similar microbiological FC quality of composting for all concentrations, revealing that it is a weak technology from a cost-effective point of view. Slacked lime with 30 and 15% (weight/weight) concentrations achieved FC zero (0) UFC g^{-1}, meeting the Environmental Protection Agency EPA standard for a class A. This situation can be associated with raising the pH. For 8% (weight/weight) concentration microbiological quality was lower than the former and did not achieve a class A.

Palabras Claves: Biosolids, Chemically Enhanced Primary Treatment, Composting, Alkali treatment.

Resumen
Este estudio tuvo como propósito evaluar dos alternativas de reducción de patógenos; Compostaje y tratamiento alcalino en los biosólidos generados en la Planta de Tratamiento de Aguas Residuales de Cañaveralejo (PTAR-C), de Cali, Colombia. Para el compostaje se utilizó: Biosólidos; Biosólidos (B) + cachaza (C)+ residuos de poda (P); Biosolido (B) + Residuos Organicos de mercado (ROPM) + residuos de poda (P), por 61 días. El tratamiento alcalino se desarrollo por 13 días. Cal apagada y ceniza de carbón fue aplicada a: Biosólidos y al producto final del compostaje. Fueron 8, 15 y 30 % (peso/peso) las concentraciones aplicadas de ambos tipos de alcalinizantes. pH, humedad, temperatura, demanda química de Oxigeno (DQO, Nitrogeno Total Kjeldahl (NTK), Nitrogeno amoniacal (N- $NH_{4)}$, huevos de helmintos y coliformes fecales (CF) se monitorearon en ambos experimentos. Los resultados mostraron que la mejor mezcla de compost fue (B + C + P), eliminado patógenos, manteniendo la clasificación del material como Clase B, con una media geométrica para CF de $4x10^{-3}$ UFC g^{-1}, indicando que el proceso no alcanza la clase A. La estabilización alcalina mostró que la ceniza para todas las dosis aplicadas produjo una calidad microbiológica de CF similar al compost, mostrando cierta debilidad de este material en su poder higienizante desde el punto de vista costo-eficiencia. Cal apagada al 15 y 30% produjo mejor calidad microbiológica con cero UFC g^{-1} de CF, alcanzando el estándar de clase A según la Agencia de Proteccion Ambiental. Esta situación puede estar asociada al incremento de pH. Para el 8% (peso/peso) la calidad fue menor a las dos anteriores y no alcanzó el estándar de clase A.

Keywords: : Biosólidos, Tratamiento primario avanzado, Compostaje, Tratamiento alcalino.

1. Introduction

The use of wastewater sludge in agriculture is a practice that from few decades has been extended throughout the world (Mendez et al, 2002). Sludge arising during treatment of domestic municipal wastewater presents a valuable source of organic matter, nutrients (phosphorus and nitrogen) and other traces elements. The facts, Wastewater treatment plants (WWTP) are localized in suburbs of towns and village in close vicinity of intensively used soils offered an optimum solution for utilizing surplus sludge in agriculture. Despite these positives aspects, there are, however certain risk factors as well.

One of the most significance risk aspects is the presence of pathogens in the sludge (Plachá et al, 2007). Sludge may content a variety of pathogenic microorganisms, i.e., bacteria such as *Salmonella* species, *campylobacter jejuni, eschericha coli*, parasites and helmints eggs (Vanotti et al., 2005).

Lime stabilization is often used for sewage sludge treatment because it is cheap and effective when properly applied to stabilize sewage sludge. During lime stabilization, pH is raised to above 12 for pathogen inactivation (Krach et al., 2008).

The Chemically Enhanced Primary Treatment (CEPT) is a technology used in several big cities around the world for wastewater treatment. This technology obstacle is the enormous amount of sludge produced. Treatment and disposal of large quantities of sludge are becoming more demanding, since dewatering and drying require an extensive energy input, therefore costs increase considerably. Also, the large amounts of biosolids need safe disposal sites being this one of the main problems in large cities in developing countries (Méndez et al, 2002). Cali is the second most populated city in Colombia (2.2 million), located at southwest of the country. Public services coverage of Cali is 98% and 97% for water supply and sewage, respectively. Empresas Municipales de Cali (EMCALI) is the municipal water treatment company. The Cañaveralejo wastewater treatment plant (PTAR-C) started operations five years ago, treating almost 5.6 $m^3\ s^{-1}$, equivalent 70% of the wastewater of Cali (Torres et al, 2009)The treatment plant produces 100 t d^{-1} of sludge, which is treated by thickness, anaerobic digestion, and mechanic dewatering. The biosolids are classified as class B, EPA (2003). The sludge treatment may pose risks to public health due to its poor microbiological quality. However it may also cause an adverse environmental impact upon soil quality. In this context, the general objective of this research was to evaluate two technologies (composting and alkali) for pathogens reduction of biosolids from PTAR-C with use agriculture purposes..

2. Materials and methods

This research was developed in two phases: *i) The composting stage*, when the biosolids were composted by using additional materials, and *ii) the alkali treatment*. In this context, the experimental phase for both composting and alkali stabilization was carried out in a pilot composting unit located at the Cañaveralejo Wastewater Treatment Plant (PTAR-C).

For both phases, the experimental design used was completely random where it is assumed that all experimental units are homogeneous and treatments were randomly assigned. The project started with composting of biosolids according to data from previous research (Torres *et al*., 2005). That project worked with a mixture of biosolids and other materials to improve the physical-chemical quality of the composted biosolids. Four experimental units (piles) of 1.5 t each one were used (with two replicates). Time allowed for the experiments was 61 days. Table 1 shows the conformation of each experimental unit.

For alkali sanitization, the experiment was carried out in the same site of composting. Total weight of material (alkali + material) was 20 kg. Wood boxes (0.4 m wide, 0.5 m long and 0.4 m deep) were used as experimental units. Regarding with several experiences, the contact time required for complete reduction of pathogens with alkaline stabilization varies between 5 and 30 days with almost 100% removal efficiency of pathogens after 7 days (Boost and Poon, 1998, Madera et al., 2002, Bina et al, 2004, Araque, 2006; Plachá et al., 2008; Torres et al, 2008). For this study 13 days of

Table 1. Experimental unit for composting research

Experimental unit	Proportion by weight, w/w %
1*	100% Biosolid (B)
2*	100% filter press mud (C)
3	54% Biosolid + 36% Organic waste from open market (ROPM) + 10% pruning trees (P)
4	72% B + 18% C + 10% P

*Experimental units 1 and 2 were used as a control, and 3 and 4 as a mixture.

Table 2. Control parameters

Parameter	Sampling Frequency	Analytical Methods
Temperature (ºC)	Daily, Morning	100 ºC Thermometer, with 60 cm of bulb.
pH	3 times / week	pH metre Method.
Moisture (%)	3 times/ week	Gravimetric Method.
Aeration	2 times / week	Thermopile phase Turning. Frequency reduced once per week/ maturity phase.
Water add (irrigation)	Depending on Moisture	Manual water addition only during turning of the pile
Organic Carbon, Total N and Ammonia Nitrogen	Beginning and end of process	Digestion and titration.
K, Ca, Mg, Na, Fe, Cu Zn, Mn and B	Beginning and end of process	Spectrophotometer
Helminths eggs	Beginning and end of process	Bailenger (1979) modified.
Faecal and total coliforms and Enterobacters	Beginning and end of process	Plate count

experimental time was choose, counting the day 0 as the day of application of alkali material. Controlling and evaluating parameters and the determination techniques were similar to those composting, they are all listed in Table 2.

Doses between 15 to 60% of lime have been used for sanitization of biosolids (Barros et al, 2005; Araque, 2006). Regarding with the work of Torres et al, 2009, in this study different doses (in a weight-to-weight proportion) were used with one replicate and blank unit, which were evaluated too. 28 units were employed and located randomly in the pilot area. Table 3 describes the treatments and evaluations. For both experiments (composting and alkali) all parameters were measured according with APHA (1995).

Table 3. Alkali stabilization treatments

Treatment number	Composition	Alkali Material	Alkali, % w/w
1 and 8*	Control		
2	100% Biosolid	Hydrated lime	30
3			15
4			8
5		Ash	30
6			15
7			8
9	Mixture: 72% Biosolid + 18% (C) Filterpress mud + 10% pruning trees (P)	Hydrated lime	30
10			15
11			8
12		Ash	30
13			15
14			8

* Samples from each compost without alkali material

3. Results and discussions

Regarding to the experimental set up, the results will be given in the same order as the research was carried out.

3.1 Composting

General results for each treatment (piles) are shown in Table 4**.** Treatment with 72% B + 18% C + 10% P presented the best performance for physical-chemical and microbiological characteristics. Regarding to the values (Table 4) the material will also classify as a class A compost (EPA, 2003).

The C/N ratio was very little for all treatments except for the filter press mud (C, which was 21) at the beginning of the composting process. This situation was inferior at the end of the stage since the ratios were less than 8 for all materials. The results showed that heavy metals behaved steadily, because their ratios were inferior to EPA (2001) standards.

Concerning temperature, Figure 1 shows the behaviour of the average temperature in the controls units (B and C) and mixtures evaluated. With regard to the control units found that for the treatment of 100% C, the thermophilic phase (temperatures above 50 ºC, Kiely, 1999) started from day 11, whereas 100% B reached this stage, 6 days after. Mixtures showed similar behaviours in terms of temperature.

Treatments 3 and 4 (Table 3) showed greater retention time of the temperature above 55 ºC (42 and 35 days respectively) than those in the study by Torres et al., (2005) where they remained about 15 to 17 days each of the mixtures, this situation which could be attributed to the heterogeneity of organic waste management (treatment 3) and pile turn times and irrigation of each cell.

As to the permanence of the high temperatures favouring the elimination of pathogens, some strict regulations compost quality as Standard 503 of the U.S. EPA (EPA, 2003) provide a minimum temperature for the elimination of pathogens 55 ºC for 15 days. Likewise, Kiely (1999) also recommend the same range of temperature and

Table 4. Initial and final characteristic of biosolids treatments and blank

	Initial data				Final data				
Piles	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	
Parameter	**100B**	**100C**	**54B+36R OP +10P**	**72B+18C +10P**	**100B**	**100C**	**54B+36R OP +10P**	**72B+18C +10P**	**Recommended quality**
pH	6.6	6.9	6.5	6.7	6.1	7.5	6.4	6.3	4 – 9 (1) and 5 – 8.5 (2)
Moisture (%)	62.8	60.3	64.7	60.2	33.8	37.7	33.7	35.1	30 – 45 (2)
Organic Carbon (%)	18.5	20.2	18.6	19.0	12.0	11.0	5.6	7.0	> 26.1 Class A > 14.5 Class B (2)
TKN (%)	2.3	1.0	1.8	1.3	1.8	1.4	1.6	1.7	> 0.8 (2)
$N\text{-}NH_4$ (%)	0.30	0.04	0.13	0.26	0.10	0.01	0.03	0.10	= 0.04 (2)
Boron (ppm)	242	133	144	149	71	72	67	83	< 200 (2)
Electric conductivity (ms/cm)	6.4	3.0	7.8	6.5	6.25	3.8	11.0	6.2	< 300 (2)
Total Coliforms (FCU/g)	$2.1 x10^7$	$1.6 x10^4$	$4.2 x10^7$	$4.2 x10^7$	$2.8 x10^3$	$1.9 x10^2$	$1.0 x10^4$	$3.4 x10^4$	
Faecal Coliforms (FCU/g)	$1.3 x10^7$	$1.6 x10^4$	$4.2 x10^7$	$1.4 x10^7$	$3.0 x10^2$	$4.5 x10^1$	$6.7 x10^3$	$7.4 x10^2$	<1,0 $x10^3$ Class A (1 and 2)
Helminth eggs (No/g)	6.5	0	0	0	0	0	0	0	< 1/4 Class A (1 and 2)

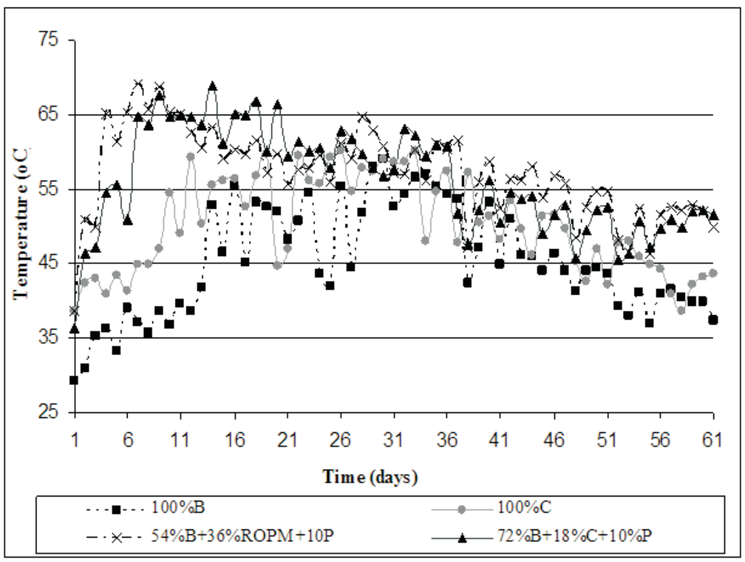

Figure 1. Temperature behaviour during composting test.

residence time suggests temperatures above 70 ºC for one hour. According to the above, among the control units only 100% C meets the requirement of the EPA with temperature above 55 ºC and temperatures above 65 ºC for 4 days, while the mixtures are able to stay temperatures above 65 °C almost double the time that control (Table 5) possibly removing pathogens increased in these treatments

The contribution of support material and amendments in compost process was important and reflected in the increase of temperature and the early onset of the thermophilic stage. However, maintaining temperatures at or greater than 67 º C generated by the volatilization of compounds such as carbon and nitrogen (Sundgberg, 2005), materials needed for a good end from the agricultural point of view, so it is necessary control these temperature increases during the process.

All treatments presented good microbiological quality of the composted material, helminth eggs were absented during research and coliforms were lower than EPA (2003) recommendations. It is important to maintain the microbiological quality of the material when compost is used in agriculture, because previous works in the Canaveralejo WWTP (Torres et al., 2005) revealed that occasionally the quality is lesser with compost being classified as B (EPA, 2003).

Finally, the pH of selected treatment (72% B + 18% C + 10% P) was slightly lower and with acid tendency, shows that this factor does not contribute with pathogens removal from biosolids. The moisture was reduced by 58%, reached the recommended valour when this product is planned to be use for agriculture purpose (CONAMA, 2000).

3.2 Alkali stabilization

Unit with 30% of hydrated lime (treatment 2) present the highest temperature (T) value, fluctuating between 34 and 38 ºC. This parameter remained low for the rest of the experimental units. This small increase of Temperature was possibly due to exothermic reaction when lime was applied to the material. However, two hours after the experiment started, the temperature sunk and this condition was similar for the other treatments. The lime reactions were similar, although with lesser values at the condition reported in other studies (Clemente et al., 2005, Madera et al., 2002, Boost and Poon, 1998), where temperature increased sharply, but it dropped fast after a short time to reach almost environmental temperature.

With respect to the ash units, temperature remained similar to the control unit (100% B without alkali products). Temperature value being almost 25 ºC, showed that the effect of ash in the process was probably small, since this parameter (temperature) remained stable, opposite as recommended by EPA (2003).

Treatment mixtures of compost and doses with 30% and 15% of lime raised the temperature to 37 ºC, approximately. After a couple of hours, the temperature dropped to ambient temperature (24 ºC), similarly to the control unit. This situation was comparable in the compost with 100% B as well. Regarding to ash, there was no real differences; the values being around 25 ºC during the first 7 days and reduced to 22 ºC thereafter.

Experimental units with 100% B and mixtures using lime presented high pH values from the first day, reaching 12 units as maximum (inhibitor value for pathogens). This condition was maintained for more than 72 hours, the recommended time by EPA 503 (2003). The potential effect of pH in pathogen reduction will be higher, a situation confirmed by microbiological data, where a 30 and 15% of lime doses reached no detected coliforms/g. Given these results and the physical-chemical quality of the final product, a 15% of hydrated lime doses were considered the best, because the pH was close to 12 for more than 3 days, after 5 days the moisture was reduced to 20% (recommended value for compost) and after 6 days, coliforms were zero with a lower reduction of organic matter and nutrients compared to the 30% dosage. Additionally, the use of lime can reduce the potential bacterial re-growth.

The ash experimental units presented insignificant changes, the pH increased to 9 units. Probably, pathogen reduction was poor, especially for

Table 5 Temperature behaviour during composting test

Treatment	Maximum reached temperature (ºC)	Time (days) with temperature > 55ºC	Time (days) with temperature > 65ºC
1 (100%B)	59.0	8	0
2 (100% C)	67.7	40	4
3(54B+36ROPM+10P)	69.1	42	7
4 (72B+18C+10P)	68.9	35	8

coliforms. The type of ash used was poor, indicating that it is necessary to explore other sources of this material. Microbiological quality is shown in Table 6.

All hydrated - lime doses applied in 100% B were optimal and met the standards for class A (EPA, 2003). Only 8% presented high coliforms values, probably because the amount of lime used was insufficient for these types of materials (bio-solids have higher pathogen content). The three proportions used reached values below EPA (2003) guidelines for mixtures of compost with lime. Test data showed these samples never reached the EPA (2003) standard for ash.

The results showed than lime stabilization method to be an effective in disinfecting sludge contained pathogenic bacteria. No pathogens were isolated from the biosolids and this observed condition is similar to that found in others works (Boost and Ponn, 1998, Placha et al., 2008).

These results confirmed the EPA recommendation concerning high microbiology quality, which can be reached by keeping pH above 12 units for more than 3 days, even if the temperature obtained was lower than 52 ºC.

4. Conclusions

Biosolids from the WWT of Cali (PTAR-C) have large amounts of pathogens (1. 7 x 105 CFU/g faecal coliforms and positive helminths eggs presence); meaning this material poses a high publics health risk. For safe management and disposal, the biosolids require treatment as to achieve the EPA 503 (2003) quality standards. In this sense, both composting and alkali stabilization play a very important role to obtain this goal.

The final compost obtained in this research met the Colombian standard NTC 5167 (ICONTEC, 2003), for organic matter planned to be use in agriculture or soil conditioning; the Chilean standard (CONAMA, 2000) for class B compost

Table 6. Total and faecal coliforms for alkali research

Day		**1**		**2**		**7**		**14**	
		Coliforms (x 10^3/g sample)							
Treatment		**Totals**	**Faecal**	**Totals**	**Faecal**	**Totals**	**Faecal**	**Totals**	**Faecal**
Compost 100% Biosolid	Control	75	4.0	120	1.0	100	0.07	70	0.6
	30% lime	1.0	0	1.0	0	7.0	0	0.3	0
	15% lime	27	0	20	5.8	3.0	1.3	1.3	0
	8% lime	2.0	0	17	0	30	0.8	100	1.6
	30% ash	47	10	50	2.0	46	0	230	5.0
	15% ash	66	0	90	20	5.2	0	94	0.8
	8% ash	30	1.5	130	4.0	56	0.1	99	1.0
Compost Mixture	Control	71	0.9	910	2.0	27	0	6200	1.1
	30% lime	2.0	0	8.0	0	5.0	0	95	0
	15% lime	0,9	0	3.0	0	5.0	0	5.0	0
	8% lime	1.1	0	21	0	19	0	7,0	0
	30% ash	53	16	120	0.4	5.0	0	88	11
	15% ash	52	4.9	100	20	27	0	1000	0.4
	8% ash	38	26	2400	800	2.2	0	1500	0.1

was met for pH, moisture, nitrogen and heavy metal parameters. Mixtures of compost obtained the best results, confirming that use of materials such as the filter press and pruning trees may improve the process and lead to a better product.

Alkali stabilization with composted biosolids and a mixture using hydrated lime, obtained the best results from the microbiological point of view with a performance higher that other studies reported in the scientific literature (Boost and Ponn, 1998, Placha et al., 2008). The lime produced high pH values and maintained them for more than 3 days – enough time for pathogen removal according to EPA (2003). This effect was confirmed with microbiology analyses, where results showed 0 UFC /g, 6 days after the starting of the research.

The recommended dose was 15%, because this has the same behaviour as a 30% one and better than 8%, but however the amount of lime was lower, including cost as a criterion for selection of the dose.

In this work, alkali stabilization with lime reached the best performance than composting from microbiological perspective, showing that if biosolids are planned to use in agriculture, alkali can be first option for treatment and even though it depends on the amount of biosolids, the cost can be low because it is unnecessary large areas for processing and storing material as composting required.

Alkali stabilization using ash was poor because the pH does not arise; pathogens were detected in the final product and for this reason the final alkali compost did not classify as a class A or B (according to the EPA, 2003, standards).

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